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REVIEW ARTICLE

Components of Standing Postural Control Evaluated in Pediatric Balance Measures: A Scoping Review

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Abstract

Objective: To identify measures of standing balance validated in pediatric populations, and to determine the components of postural control captured in each tool.

Data Sources: Electronic searches of MEDLINE, Embase, and CINAHL databases using key word combinations of *postural balance/equilibrium*, *psychometrics/reproducibility of results/predictive value of tests*, and *child/pediatrics*; gray literature; and hand searches.

Study Selection: Inclusion criteria were measures with a stated objective to assess balance, with pediatric (≤18y) populations, with at least 1 psychometric evaluation, with at least 1 standing task, with a standardized protocol and evaluation criteria, and published in English. Two reviewers independently identified studies for inclusion. There were 21 measures included.

Data Extraction: Two reviewers extracted descriptive characteristics, and 2 investigators independently coded components of balance in each measure using a systems perspective for postural control, an established framework for balance in pediatric populations.

Data Synthesis: Components of balance evaluated in measures were underlying motor systems (100% of measures), anticipatory postural control (72%), static stability (62%), sensory integration (52%), dynamic stability (48%), functional stability limits (24%), cognitive influences (24%), verticality (9%), and reactive postural control (0%).

Conclusions: Assessing children's balance with valid and comprehensive measures is important for ensuring development of safe mobility and independence with functional tasks. Balance measures validated in pediatric populations to date do not comprehensively assess standing postural control and omit some key components for safe mobility and independence. Existing balance measures, that have been validated in adult populations and address some of the existing gaps in pediatric measures, warrant consideration for validation in children.

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Balance is defined as the ability to control the center of mass relative to the base of support.[1] Described as both a structure/function and activity within the *International Classification of Functioning, Disability and Health* framework,[2] the ability to achieve and maintain balance in upright stance is a critical and complex lifelong skill. Commonly observed impairments in postural control among pediatric populations, traditionally defined as those ≤18 years, are associated with delayed motor development and mobility function.[3,4] Fortunately, impairments in standing balance can be effectively treated through therapeutic exercise.[5-7] Accordingly, assessment of postural control in standing is important for monitoring development, diagnosing impairments, planning treatment programs, and evaluating change in pediatric populations.

The assessment of standing balance in pediatric populations is complicated both by its multicomponent structure and by the influence of development on postural control. The multicomponent nature of balance is reflected in contemporary postural control

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theory, which has adopted a systems perspective that conceptualizes balance as the product of interaction among multiple biologic systems in a continuously changing environment.[8-11] Although no unified description of a systems perspective to postural control has been ratified, the approach is supported by evidence from multiple laboratories demonstrating how imposed constraints or deficits in ≥1 underlying systems impair balance and affect development of postural control.[12] Commonly described balance components in pediatric and adult populations include underlying motor system elements (eg, strength, coordination), static stability during quiet standing, limits of stability affecting the ability to move the center of mass as far as possible within the base of support, orienting relative to gravity, postural reactions to recover stability, anticipatory adjustments prior to discrete voluntary movements, dynamic stability when the base of support changes, integrating sensory information, and influence of cognitive processing on the maintenance of stability (table 1).[10,12,14-16] A systems perspective to postural control highlights the importance of considering each component individually because each can independently lead to balance impairment. Furthermore, development of each of these components takes place over multiple years, with neurophysiologic and biomechanical evidence suggesting that adult-like postural control requires approximately 7 years from birth to mature.[1] As such, there is much diversity regarding how pediatric balance may be expected to present within this time frame.

The intersection of systems and developmental considerations on postural control emphasizes the need for assessment of each component and tailored treatment on a case-by-case basis. Choosing an appropriate measure of balance has important implications for diagnosis, prognosis, and treatment, and content validity should be a primary consideration given the recognized absence of a criterion standard for evaluating balance.[17] However, evidence based on adult data suggests that commonly used measures of standing balance do not comprehensively assess postural control. A 2015 scoping review of 66 standing balance measures validated in adult populations showed that most did not examine all relevant balance components for functional mobility and fall avoidance.[13] Although recent reviews of postural control assessment and functional balance tests in pediatric populations have focused on specific impairments,[18] psychometric properties, and some components of balance,[19] none have explored the content of the measures using a comprehensive systems perspective. Furthermore, to our knowledge, no reviews to date have examined the stage of postural development considered in the development of pediatric balance measures.

Systematically examining the underlying constructs in pediatric balance measures is critical to improving understanding of the strengths and limitations of balance measures, and for facilitating selection of optimal measures for clinical use and future research. The primary objectives of this study were (1) to identify measures of standing balance for pediatric populations, and (2) to determine the components of standing postural control captured in each measure using a systems perspective. A secondary objective was to examine how developmental considerations for balance were accounted for in the development or initial pediatric testing of each measure. The review was guided by the following question: Which components of standing postural control are evaluated in balance measures whose validity or reliability are established in pediatric populations (≤18y)? The findings may be useful in developing recommendations for more standardized use of balance outcome measures in pediatric rehabilitation research and clinical practice.

List of abbreviations:

BESTest	**Balance Evaluation Systems Test**
BOT-2	**Bruininks-Oseretsky Test of Motor Proficiency, Second Edition**
PDMS-2	**Peabody Developmental Motor Scales, Second Edition**

Methods

A scoping review was conducted.[20] Scoping reviews are rigorous knowledge syntheses that comprehensively summarize evidence to inform policy, practice, and future research.[21] We applied Arksey and O'Malley's 5-stage framework for scoping reviews[20] and incorporated recent recommendations for enhancing this methodology[22,23] (eg, using an iterative approach to develop the research question with stakeholder involvement, defining relevant concepts, including quality indicators in the eligibility criteria). Preferred Reporting Items for Systematic Reviews and Meta-Analyses recommendations for systematic review conduct and reporting[24] also informed the methodology, and were adopted where appropriate.

Data sources and searches

A professional librarian developed the search strategy, which was reviewed by a second librarian. Published literature indexed in MEDLINE (1946 to December 1, 2015), Embase (1974 to December 1, 2015), and CINAHL (1981 to December 1, 2015) was searched. Combinations of the following terms were used: *postural balance/equilibrium*, *psychometrics/reproducibility of results/predictive value of tests*, and *child/pediatrics*. A sample search strategy for MEDLINE is presented in supplemental table S1 (available online only at http://www.archives-pmr.org/). A comprehensive hand search was also conducted to identify measures not captured by database searches, including a search of published narrative review articles describing balance measures identified in the database search, the Health and Psychosocial Instruments database, and a search for pediatric validation of measures identified in a previous scoping review of balance measures for adult populations.[13] In addition, a local team of practicing pediatric physical therapists were consulted to identify additional measures commonly used to assess balance potentially not identified by the search.

Study selection

Level one title and abstract screening criteria included descriptive studies which (1) focused on balance measurement, (2) included pediatric populations (≤18y), and (3) were published in the English language. Screening criteria were piloted on a random 10% sample of abstracts and clarified where necessary. The search was specific for index publications—a measure's first publication presenting its development and/or initial psychometric evaluation—and/or initial psychometric evaluation in pediatric populations for consideration as a measure's definitive reference. However, in anticipation that not all measures would be published in a way that it would be possible to identify the first publication from the abstract, the names of all balance measures identified in the abstract screen were recorded for manual cross-checking and hand search for the index publication. Teams of 2 research assistants with health sciences backgrounds and graduate research training independently screened abstracts of studies identified in the database search using the screening criteria. The principal investigator, who also reviewed the list of all measures identified in the abstract screening, resolved disagreements and flagged relevant abstracts for follow-up hand search. The principal investigator had an educational background in kinesiology with graduate training in rehabilitation and medical sciences focused on fundamental and clinical research in postural control.

Level 2 full-text screening criteria included (1) index publication in pediatric population, (2) have a stated objective or commonly used to assess balance, (3) include at least 1 standing task, (4) have both a standardized testing protocol and standardized evaluation criteria, and (5) evaluate a minimum of 1 psychometric property (validity or reliability). The last criterion (minimum of 1 psychometric property evaluated) was included for quality assessment purposes to prevent inclusion of measures with no empirical support. Hand searches were triggered at this phase if (1) no psychometric data were reported in the index publication (to determine whether companion articles existed that would support inclusion of the measure in the review); or (2) it was not clear from the full text whether the identified article was the index publication. Full-text screening was performed by teams of 2 research assistants, with disagreements resolved by the principal investigator. The preliminary list of included measures was reviewed and discussed by a local team of practicing pediatric physical therapists to confirm inclusion of all known relevant measures.

Data extraction and quality assessment

Descriptive data abstraction was performed by teams of 2 research assistants and reviewed by the principal investigator. A standardized template was used to extract the measures' stated purpose and development methods, characteristics (evaluation parameters and number of items), and results of preliminary psychometric testing (pediatric population and age range, and reliability and/or validity).

The components of balance evaluated in each measure were explored by coding the individual test items and tasks using a systems perspective to postural control. Operational definitions for 9 components of balance were applied from a previous review of standing balance measures in adult populations[13] after confirming that all components were identified as relevant to pediatric populations in the literature.[10,14-16] Several pediatric balance measures were identical to the adult version (with respect to test items, evaluation criteria, and referenced associated index publication for adult populations), and the coding scheme from the previous scoping review of adult balance measures[13] was adopted for these pediatric measures. For all other pediatric measures, 2 investigators independently reviewed the tasks and scoring criteria of each measure and identified on a binary scale (yes/no) which balance components were included in each measure. Individual components were defined as included if they were integral to task performance, even if not explicitly part of the measure's evaluation criteria. Shumway-Cook and Woollacott's reference[1] of 7 years to reach postural maturity was used to determine whether each measure's initial development and psychometric testing occurred in children who were in the development phase of postural control (study age, <7y), fully matured (study age, 7−18y), or crossed the postural development continuum. Disagreements were resolved through consensus discussion with a third investigator.

Data synthesis and analysis

Figure 1 illustrates the study selection process. The MEDLINE, CINAHL, and Embase searches yielded a total of 1405 records. The hand search and Health & Psychosocial Instruments search yielded an additional 59 records. After removing duplicates, 1283 abstracts were identified for screening. Of these, 155 articles were selected for full-text review. After full-text screening, 21 measures met the inclusion criteria.[25-45] During review and consultation with the local team of practicing pediatric physical therapists, an additional 3 measures were identified that included a clinically relevant standing balance component within a broader developmental motor measure.[46-48] Although these measures did not meet the criteria of a balance measure for this review, because clinicians conceived these measures as useful tools for assessing balance, they were also coded against the Systems Framework for Postural Control as an addendum to the full review. Data abstraction and mapping results were tabulated, and descriptive statistics were calculated for all variables.

Results

Measure characteristics

Table 2 presents selected characteristics of each measure. The 21 measures were published or first used in pediatric populations between 1990 and 2015. Most measures (17/21, 81%) were developed in adult populations and subsequently validated for use with pediatric populations. The remaining measures were developed specifically for children either through consultation with clinicians (n=2; Pediatric Reach Test[43] and Early Clinical Assessment of Balance[45]) or by unreported methods (n=2; Ghent Developmental Balance Test[27] and Timed Up and Down Stairs Test[41]). The number of items in each measure ranged between 1 and 35, with a median of 4 items. One measure included graded progression in which participants must meet specific criteria to complete additional items. Fourteen measures (67%) were evaluated on a continuous scale, and the remaining 7 measures used a categorical scale with 2 to 7 categories. One measure (Ghent Developmental Balance Test[27]) was criterion-referenced, whereas the other 20 measures were norm-referenced. Both reliability and validity statistics were presented in the original report for 10 measures (48%), whereas 9 (43%) presented reliability only, and 2 (9%) presented validity only in the original report. Detailed psychometric data published with the index pediatric publication are presented in supplemental table S2.

Components of balance evaluated and postural development considerations in each measure

Of the 21 included pediatric balance measures, 12 were identical to the adult-validated version and the codes were adopted from the previous adult review.[24] Among the 9 newly coded measures, coding agreement by the 2 independent reviewers was 94%. Total agreement was achieved after consensus discussion with a third reviewer. Coding results identifying the components of balance included in each measure are presented in table 3. Underlying motor systems were evaluated in all 21 measures, anticipatory postural control in 15 measures (72%), static stability in 13 measures (62%), sensory integration in 11 measures (52%), dynamic stability in 10 measures (48%), functional stability limits in 5 measures (24%), cognitive influences in 5 measures (24%), verticality in 2 measures (9%), and reactive postural control in 0 measures. All measures included between 3 and 6 components of balance; no measures included all 9 components.

Table 1 Components of balance operational definitions[13]

Component	Definition/Example
1. Functional stability limits	Ability to move the center of mass as far as possible in the anterior-posterior or mediolateral directions within the base of support
2. Underlying motor systems	For example, strength or coordination
3. Static stability	Ability to maintain position of the center of mass in unsupported stance when the base of support does not change (may include wide stance, narrow stance, 1-legged stance, tandem—any standing condition)
4. Verticality	Ability to orient appropriately with respect to gravity (eg, evaluation of lean)
5. Reactive postural control	Ability to recover stability after an external perturbation to bring the center of mass within the base of support through corrective movements (eg, ankle, hip, stepping strategies)
6. Anticipatory postural control	Ability to shift the center of mass prior to a discrete voluntary movement (eg, stepping—lifting leg, arm raise, head turn)
7. Dynamic stability	Ability to exert ongoing control of center of mass when the base of support is changing (eg, during gait, postural transitions)
8. Sensory integration	Ability to reweigh sensory information (vision, vestibular, somatosensory) when input altered
9. Cognitive influences	Ability to maintain stability while responding to commands during the task or attend to additional tasks (eg, dual-tasking)

Two of the 21 measures (9%) were initially tested in children developing postural control (study age, <7y), 7 (33%) were initially tested in individuals with mature postural control (study age, 7−18y) only, and 12 (57%) were initially tested with individuals across the postural development continuum.

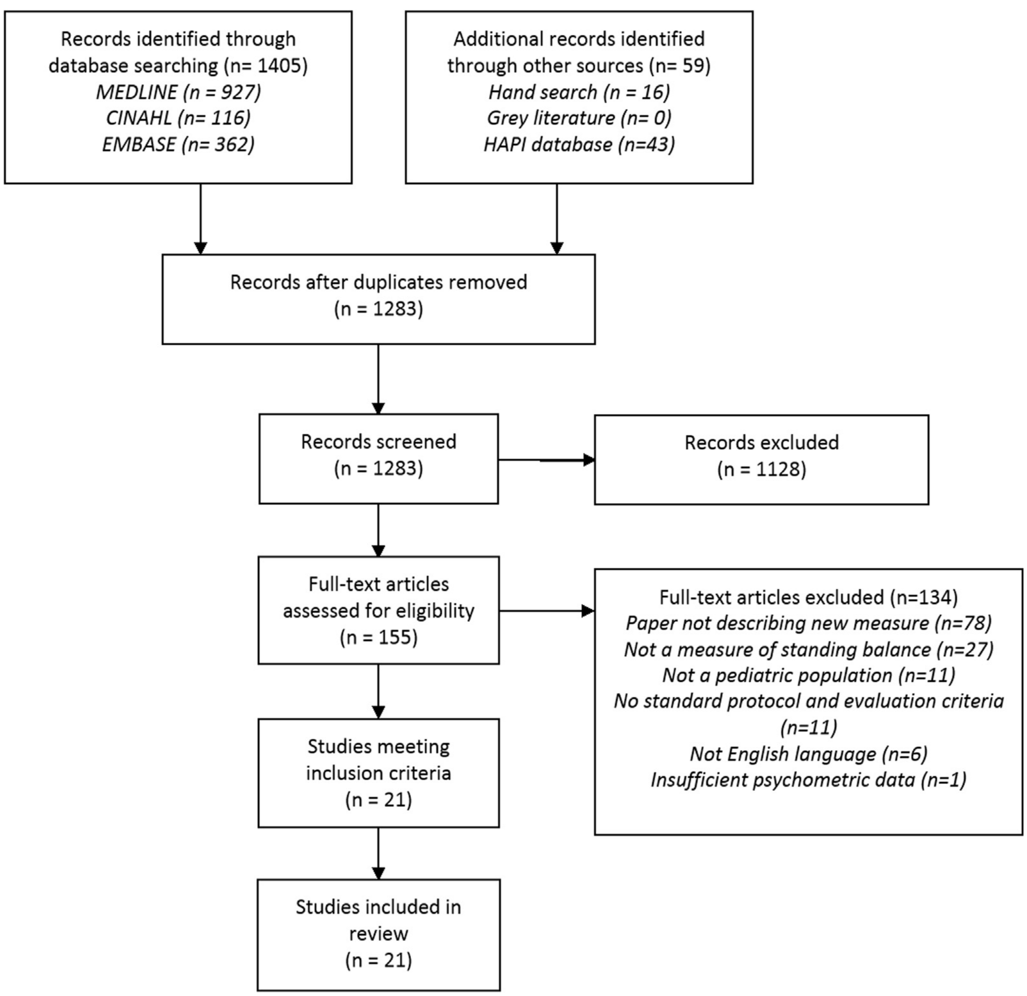

Fig 1 Study flow diagram. Abbreviation: HAPI, Health and Psychosocial Instruments.

Table 2 Selected characteristics of balance measures validated in pediatric populations

Measure	Reference	Stated Purpose of Measure	Components of Balance Purportedly Assessed	Target Pediatric Population	Development Methods	No. of Items in Test	Evaluation Parameters	No. of Scoring Categories	Graded Progression	Initial Pediatric Age Range Validated
Balance Error Scoring System	Valovich McLeod et al[33]	Not specified	Not specified	Youth sport participants	Developed in adult population (Riemann)[49]	6 (3 stances, 2 surfaces)	Continuous (no. of errors), criterion referenced	N/A	No	9–14y
Modified Balance Error Scoring System	Hunt et al[39]	Evaluate postural stability after concussion	Not specified	High school athletes	Modified from adult version adult population (Riemann)[49]	4 (2 stances, 2 surfaces)	Continuous (no. of errors), criterion referenced	N/A	No	13–19y
Community Balance and Mobility Scale	Wright et al[38]	Assess high-level balance that mimics requirements underlying community mobility skills	Not specified	Children with acquired brain injury	Developed in adult population (Howe)[50]	20 (13 items, 6 performed bilaterally)	Categorical, criterion referenced	4	No	7–18y
Dynamic Gait Index	Lubetzky-Vilnai et al[30]	Quantify dynamic balance abilities and evaluate individual's ability to modify gait in response to changing task demands	Mobility function and dynamic balance in walking and stair-climbing	Children developing typically, children with fetal alcohol spectrum disorder	Developed in adult population (Shumway-Cook and Woollacott)[51]	8	Categorical, criterion referenced	4	No	8–15y
Five Times Sit to Stand Test	Kumban et al[26]	Measure lower limb strength and balance ability	Not specified	Children with mild to moderate cerebral palsy	Developed in adult population (Whitney et al.)[52]	1	Continuous (time), criterion referenced	N/A	No	6–18y
Four Square Step Test	Bandong et al[37]	Assess balance in the presence of task and environmental constraints	Not specified	Children with developmental disabilities	Developed in adult population (Dite and Temple)[53]	1	Continuous (time), criterion referenced	N/A	No	5–12y
Functional Reach Test	Donahoe et al[42]	Measure distance reached beyond arm's length while maintaining a fixed standing position in children	Dynamic balance, strength, biomechanics, proprioception, vestibular mechanisms, and motor planning	Children developing typically	Developed in adult population (Duncan)[54]	1	Continuous (distance), criterion referenced	N/A	No	5–15y

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Table 2 (*continued*)

Measure	Reference	Stated Purpose of Measure	Components of Balance Purportedly Assessed	Target Pediatric Population	Development Methods	No. of Items in Test	Evaluation Parameters	No. of Scoring Categories	Graded Progression	Initial Pediatric Age Range Validated
Ghent Developmental Balance Test	De Kegel et al[27]	Evaluate balance in children from moment of independent walking until age of 5y	Static and dynamic balance	Children developing typically, children diagnosed with mental retardation	Not specified	35	Categorical, norm referenced	3	Yes (test starts from level of 3 consecutive scores of 2 in developmental order, continues until 3 consecutive failures in developmental order of test)	18mo—5y
High-Level Mobility Assessment Tool	Kissane et al[28]	Quantify the mobility requirements of young adults with traumatic brain injury for social, leisure, sporting, and employment activities	Not specified	Young adults with moderate to severe traumatic brain injury	Developed in adult population (Williams)[55,56]	13	Categorical, criterion referenced	5 or 6	No	6—16y
Limits of Stability Test	Alsalaheen et al[35]	Not specified	Dynamic postural stability	Adolescents	Developed in adult population	1	Continuous (reaction time, movement velocity, center of gravity excursion and endpoint, directional control), criterion referenced	N/A	No	9th to 12th grade (boys, 16.1$\pm$1.7y; girls, 15.7$\pm$1.4y)
Modified Star Excursion Balance Test	Calatayud et al[40]	Identify dynamic balance deficits and improvements, predict risk of lower extremity injury	Dynamic balance	Primary school students in school setting	Developed in adult population, administered according to recommendations by Gribble et al.[57]	3 tasks, performed for each leg 7 times (4 practice trials, 3 measurement trials)	Continuous (distance), criterion referenced	N/A	N/A	10—12y
One Leg Standing Balance Test	Atwater et al[29]	Not specified	Static posture	Not specified	Developed in adult population	1	Continuous (time), criterion referenced	N/A	No	3—14y
Pediatric Balance Scale	Franjoine et al[32]	Measure of functional balance for children	Functional balance	Children developing typically, children with known balance impairments	Modified Berg Balance Scale[58] by reordering test items, reducing time standards, clarifying directions; conducted pilot reliability testing	14	Categorical, criterion referenced	5	No	4—12y

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Table 2 (*continued*)

Measure	Reference	Stated Purpose of Measure	Components of Balance Purportedly Assessed	Target Pediatric Population	Development Methods	No. of Items in Test	Evaluation Parameters	No. of Scoring Categories	Graded Progression	Initial Pediatric Age Range Validated
Pediatric Reach Test	Bartlett and Birmingham[43]	Measure balance in children with cerebral palsy	Not specified	Children developing typically, children with cerebral palsy	Primary author consulted with 3 experienced pediatric physical therapists to reach agreement for content and protocol for modifying Functional Reach Test	6	Continuous (distance), criterion referenced	N/A	No	2–12y
Pediatric Version of Clinical Test of Sensory Interaction for Balance	Crowe et al[44]	Assess the influence of sensory interaction on balance	Sensory interaction	Children developing typically	Developed in adult population (Shumway-Cook and Horak)[59]	12 (6 sensory conditions, 2 feet positions)	Continuous (stance, duration, peak to peak amount of sway, quality— type of movement strategy), criterion referenced	N/A	No	4–9y
Posture and Postural Ability Scale	Rodby-Bousquet et al[34]	Assess postural control and asymmetries in people with severe disabilities in 4 basic body positions (supine and prone lying, sitting, and standing)	Alignment, stability in static and dynamic situations	Children with cerebral palsy	Developed in adult population (Rodby-Bosquet)[60]	4 tasks, 53 items	Categorical, criterion referenced	7 categories for postural ability, 2 categories for quality of posture	No	6–16y
Sensory Organization Test	Christy et al[36]	Determine how vestibular information is used to control posture	Not specified	Children with sensorineural hearing loss	Developed in adult population	6	Continuous (amount of sway), criterion referenced	N/A	No	6–12y
Sensory Test	Gabriel and Mu[25]	Examine organization of sensory inputs necessary to maintain postural stability and aspects of the vestibule-spinal reflex	Relative contributions of the visual, somatosensory, and vestibular systems to maintain postural stability	Children developing typically	Developed in adult population (Ford-Smith et al.)[61]	4	Continuous (sway velocity), criterion referenced	N/A	No	5–9y
Timed Up and Down Stairs Test	Zaino et al[41]	Measure of functional mobility and balance	Anticipatory and reactive postural control	Children developing typically, children with cerebral palsy	Not specified	1	Continuous (time), criterion referenced	N/A	No	8–14y
Timed Up and Go test	Williams et al[31]	Assess basic or functional ambulatory mobility of dynamic balance	Dynamic balance	Children developing typically, children with physical disability because of cerebral palsy or spina bifida	Developed in adult population (Podsiadlo and Richardson)[62], modified based on pilot tests	1	Continuous (time), criterion referenced	N/A	No	3–9y

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Table 2 (*continued*)

Measure	Reference	Stated Purpose of Measure	Components of Balance Purportedly Assessed	Target Pediatric Population	Development Methods	No. of Items in Test	Evaluation Parameters	No. of Scoring Categories	Graded Progression	Initial Pediatric Age Range Validated
Early Clinical Assessment of Balance	McCoy et al[45]	To estimate postural stability in children with cerebral palsy across all levels of functional ability	Postural stability	Children with cerebral palsy	Combination of Movement Assessment of Infants — Automatic Reactions Section and Pediatric Balance scale, items selected by consensus of pediatric physical therapist researchers and study team	13	Categorical, converted to points with various weights attached, criterion referenced	5	No	1.5–5y

Abbreviation: N/A, not available.

Consultations with pediatric physical therapists highlighted the Alberta Infant Motor Scale,[47] Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2),[48] and Peabody Developmental Motor Scales, Second Edition (PDMS-2)[46] as commonly used to assess balance, particularly in toddlers and preschool age children. Although not explicit measures of balance and therefore not included in the full review findings, conceptual mapping (table 4) revealed that all 3 measures included at least 4 components of balance: static stability, underlying motor systems, anticipatory postural control, and dynamic stability. The BOT-2 also included sensory integration, and the PDMS-2 also included cognitive contributions. Two of these measures (Alberta Infant Motor Scale and BOT-2) were initially tested in children developing postural control (study age, $<$7y), and 1 (PDMS-2) was tested with individuals across the postural development continuum.

Discussion

Synthesizing the published literature on validated balance measures for children and analyzing their content with respect to contemporary postural control theory is useful for summarizing the current state of pediatric balance measurement, and for identifying opportunities for continued development. Furthermore, engaging frontline physical therapists in vetting included measures enhances the clinical utility of the results, and in this case also identified potentially relevant measures that would not otherwise have been included. Although $>$20 validated balance measures were identified, they were not comprehensive and assessed only some key components of balance. None of the currently validated pediatric balance measures examine all 9 components of balance studied in this review. Although some components were included in a high proportion of measures (eg, underlying motor systems, anticipatory postural control, and static stability in at least 60% of measures), most measures evaluated a limited number of balance components ($\leq$3). This finding is perhaps not unexpected given that such issues were also identified in a previous review of balance measures for adult populations.[24] However, a critically important addition to this body of literature is the finding that that pediatric balance measures are even more restricted in their analysis of postural control. This is exemplified by the fnding that some components, including functional stability limits, cognitive contributions, and verticality, were not included in most measures (less than one quarter). Most importantly, not a single measure included an evaluation of reactive postural control. The absence of this component is a major limitation of existing pediatric balance measures because reactive postural control is well recognized as the most critical component of balance for fall avoidance.[63] Impaired reactive control is independently associated with falls in adults,[64] and in children, mastery of rapid compensatory steps in walking is viewed as a key milestone during development of effective balance recovery strategies.[65] Similarly, cognitive contributions and verticality were both underrepresented in existing measures and are important precursors for safe mobility (cognitive contributions) and establishing appropriate orientation (verticality).[12]

Although measures that evaluate a restricted subset of balance components may be appropriate for balance screening or fall risk assessment, a comprehensive approach is ideal for identifying impairment and treatment planning. Currently, no combination of

Table 3 Components of balance in measures used in pediatric populations

Measure	Static Stability	Underlying Motor Systems	Functional Stability Limits	Verticality	Reactive Postural Control	Anticipatory Postural Control	Dynamic Stability	Sensory Integration	Cognitive Influences	Other Constructs Not Included in Systems Framework
Balance Error Scoring System	Yes	Yes	No	No	No	No	No	Yes	No	N/A
Modified Balance Error Scoring System	Yes	Yes	No	No	No	No	No	Yes	No	N/A
Community Balance and Mobility Scale	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	N/A
Dynamic Gait Index	No	Yes	No	No	No	Yes	Yes	Yes	Yes	N/A
Five Times Sit to Stand Test	No	Yes	No	No	No	Yes	Yes	No	No	N/A
Four Square Step Test	No	Yes	No	No	No	Yes	Yes	No	No	N/A
Functional Reach Test	No	Yes	Yes	No	No	Yes	No	No	No	N/A
Ghent Developmental Balance Test	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	N/A
High-level Mobility Assessment Tool	No	Yes	No	No	No	Yes	Yes	No	No	N/A
Limits of Stability Test	No	Yes	Yes	No	No	Yes	No	No	No	N/A
One Leg Standing Balance Test	Yes	Yes	No	No	No	No	No	Yes	No	N/A
Pediatric Balance Scale	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Sitting balance
Pediatric Reach Test	Yes	Yes	Yes	No	No	Yes	No	No	No	N/A
Pediatric Version of Clinical Test of Sensory Interaction for Balance	Yes	Yes	No	No	No	No	No	Yes	No	N/A
Posture and Postural Ability Scale	Yes	Yes	No	Yes	No	Yes	No	No	No	Sitting balance
Sensory Organization Test	Yes	Yes	No	No	No	No	No	Yes	No	N/A
Sensory Test	Yes	Yes	No	No	No	No	No	Yes	No	N/A
Star Excursion Balance Test	Yes	Yes	Yes	Yes	No	Yes	No	No	No	N/A
Timed Up and Go test	No	Yes	No	No	No	Yes	Yes	No	Yes	N/A
Timed Up and Down Stairs Test	No	Yes	No	No	No	Yes	Yes	No	No	N/A
Early Clinical Assessment of Balance	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Sitting balance

Abbreviation: N/A, not available.

Table 4 Components of balance in motor development measures identified by pediatric physical therapists

Measure	Static Stability	Underlying Motor Systems	Functional Stability Limits	Verticality	Reactive Postural Control	Anticipatory Postural Control	Dynamic Stability	Sensory Integration	Cognitive Influences	Other Constructs Not Included in Systems Framework
Alberta Infant Motor Scale	Yes	Yes	No	No	No	Yes	Yes	No	No	N/A
BOT-2	Yes	Yes	No	No	No	Yes	Yes	Yes	No	N/A
PDMS-2	Yes	Yes	No	No	No	Yes	Yes	No	Yes	N/A

Abbreviation: N/A, not available.

validated balance measures can provide a comprehensive assessment in pediatric populations. Interestingly, 2 comprehensive measures—the Balance Evaluation Systems Test (BESTest)[11] and Mini-BESTest[66]—have published use in children despite no accompanying pyschometric evaluation. The BESTest is the only currently validated measure (for any population) containing all 9 components of balance examined in this review, and is the only existing measure developed with the goal of helping clinicians identify underlying postural control systems that may be responsible for poor functional balance. First published in 2009, in 2011, it was used in 5 children with cerebral palsy with Gross Motor Function Classification System scores between levels II and III participating in a study of lower body positive pressure−supported treadmill training.[67] In 2012, Pickett et al[68] used the Mini-BESTest, a shortened version of the original BESTest, in a study of balance impairment in 9 children between the ages of 6 and 17 years with Wolfram syndrome, a rare neurodegenerative disorder characterized by early onset diabetes, optic atrophy, deafness, and neurologic abnormalities. The Mini-BESTest includes 8 components of balance, missing only functional stability limits.[24] It was recently recommended by an international expert panel as suitable for a core outcome set or minimum data set for research and practice in adult populations.[69] Neither of these pediatric studies reported any adverse events in using either version of the BESTest. Given their inclusion of missing components in existing pediatric balance measures, comprehensiveness, and endorsed use in adult populations, one or both represent good candidates for initial validation in pediatric populations.

The analysis of developmental considerations in the development of pediatric balance measures demonstrated that >50% of measures were developed and/or initially validated among pediatric participants across a large age range that spanned the postural development continuum. Given the progressive development of balance in the first 7 years, in contrast to the relative stabilization of development in typically developing children around the age of 7 years, the lack of developmental specificity among these measures warrants additional examination into appropriateness for pediatric subpopulations. In particular, the absence of dedicated standing balance measures targeted at children between 1 and 5 years is noteworthy. Our clinician partners identified 3 measures failing to meet the inclusion criteria because they did not expressly aim to evaluate only balance, but included a significant balance component within the context of a motor development framework. In some cases, the balance section was just as comprehensive as some standalone balance measures included in the review. However, similar to included balance measures, none included an assessment of reactive postural control or functional stability limits or verticality. Although consulting with practicing pediatric physical therapists did not identify any superior measures, the process served to increase the clinical utility of the results by facilitating analysis of clinically relevant tools or measures that might not be flagged with common search terms, strategies, or keywords.

Study limitations

Limitations to this review include the following: (1) restricting consideration of theoretical constructs to standing postural control (ie, framework did not include, for example, seated balance), which is only 1 measure characteristic and only 1 aspect of pediatric balance; (2) no specific examination of evaluation parameters which might provide more precise information than observed behaviors; and (3) lack of consideration of the difficulty of individual items related to a particular balance component (eg, whether static stability was assessed by normal or narrow stance, tandem stance, or single-leg stance). Given the complexities of standardized balance measurement, we suggest readers interpret these findings in conjunction with previous reviews addressing some of these issues,[19,70] and available Internet resources.[71] Further, despite rigorous operational definition development and duplicate coding, specific codes may still be open to interpretation. For example, in our previous review, the commonly used Timed Up and Go test was unanimously coded as not involving cognitive contributions. However, the pediatric version had administration modifications (touching a wall target prior to turning) requiring the measure be recoded, and cognitive contributions were identified in this review. On discussion, the study team reflected that cognitive contributions could also be associated with the adult Timed Up and Go test.

Conclusions

The theoretical components of postural control included in standardized balance measures for children vary greatly, and do not provide a comprehensive evaluation of all the key elements of standing postural control. Additional balance measures validated in adult populations (eg, BESTest, Mini-BESTest) address some of the existing gaps in pediatric measures, and warrant consideration for validation in children. This review demonstrates continued work is necessary to identify and validate comprehensive balance assessment in research and practice to facilitate individualized identification of balance deficits and customization of training programs in the clinical setting.

Keywords

Accidental falls; Growth and development; Mobility limitation; Postural balance; Psychometrics; Rehabilitation; Young adult

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Supplemental Table S1 Sample search strategy (Ovid MEDLINE, 1946 to December Week 1, 2015)

No.	Searches	Results	Search Type
1	Postural Balance/	15,295	Advanced
2	((balanc* or imbalanc* or equilibrium or disequilibrium) and (body or postur* or musculoskeletal or disorder* or trunk or gait or walk* or abilit* or disabilit* or instabil*)).ti,kw.	3204	Advanced
3	1 or 2	17,027	Advanced
4	in.fs.	210,835	Advanced
5	mt.fs.	2,759,598	Advanced
6	Validation Studies/	70,783	Advanced
7	exp Psychometrics/	56,268	Advanced
8	psychometr*.ti,ab,kw. or clinimetr*.tw,kw. or clinometr*.tw,kw.	25,970	Advanced
9	exp Observer Variation/	32,881	Advanced
10	exp “Reproducibility of Results”/	285,816	Advanced
11	reproducib*.tw,kw.	105,188	Advanced
12	exp “Sensitivity and Specificity”/	432,013	Advanced
13	predictive value of tests/	148,365	Advanced
14	exp severity of illness index/	176,797	Advanced
15	exp disability evaluation/	40,828	Advanced
16	or/4-15	3,496,247	Advanced
17	exp Child/	1,568,972	Advanced
18	exp Pediatrics/	44,983	Advanced
19	exp Infant/	950,073	Advanced
20	exp Adolescent/	1,640,983	Advanced
21	exp minors/	2201	Advanced
22	exp puberty/	14,872	Advanced
23	exp School/	83,196	Advanced
24	(Infan* or Newborn* or new-born* or Baby* or Babies or Neonat* or neo-nat* or Prenat* or pre-nat* or Preterm* or pre-term* or Prematur* or pre-matur* or Postmatur* or Post-matur* or Child* or Schoolchild* or School age* or Preschool* or Kid or kids or Toddler* or Adoles* or Teen* or Boy* or Girl* or Minor or Minors or Pubert* or Pubescen* or juvenil* or youth* or Prepubescen* or Paediatric* or Paediatric* or Peadiatric* or Nursery school* or Kindergar* or Primary school* or Secondary school* or Elementary school* or High school* or Highschool*).tw,kw.	1,942,667	Advanced
25	or/17-24	3,585,444	Advanced
26	3 and 16 and 25	779	Advanced
27	exp animals/not (exp animals/and exp humans/)	4,003,250	Advanced
28	26 not 27	774	Advanced

Supplemental Table S2 Preliminary psychometric characteristics evaluated in index publication of included measures

Measure	Reliability Tested	Reliability Type	Reliability Score	Validity Tested	Validity Type	Validity Sample Size	Validity Score
Balance Error Scoring System	Yes	Test-retest	ICC=.75 (boys), ICC=.61 (girls)	No	N/A	N/A	N/A
Modified Balance Error Scoring System	Yes	Intraclass	*r*=.84 when administering 3 trials and scoring the second and third trials	No	N/A	N/A	N/A
Community Balance and Mobility Scale	Yes	1. Interrater, 2. Test-retest	1. ICC=.93, 2. ICC=.90	No	N/A	N/A	N/A
Dynamic Gait Index	Yes	1. Interrater, 2. Test-retest	1. ICC=.82, 2. ICC=.71	Yes	Construct	20 children (10 developing typically, 10 with FASD)	Significantly lower score in children with FASD compared with those with typical development (P=.01)
Five Times Sit to Stand Test	Yes	1. Interrater, 2. Test-retest	1. ICC=.88, 2. ICC=.912	Yes	Concurrent	33 children with cerebral palsy, 3 pediatric PTs	1. r=.552 with TUG (P<.01), 2. r=.561 with BBS (P<.01)
Four Square Step Test	Yes	1. Interrater, 2. Test-retest	1. ICC=.79, 2. ICC range, .54−.89	Yes	Concurrent	30 children (16 with cerebral palsy, 14 with down syndrome)	R=.74 with TUG (P<.01)
FRT	Yes	1. Interrater, 2. Intrarater, 3. Test-retest	1. ICC=.98, 2. ICC=.83, 3. ICC=.75	No	N/A	N/A	N/A
Ghent Developmental Balance Test	Yes	1. Interrater, 2. Test-retest	1. ICC=.98, 2. ICC=.99	Yes	1. Known-group, 2. Convergent and discriminant, and 3. Construct	74 normally developing children and 20 diagnosed with mental retardation	1. Known-group t_{38}=.142, P=.888; 2. Convergent and discriminant: r=.80 with BOT-2, r=.60 with PDMS-2, r=.69 with balance subscale, and r=.66 with M-ABC-2; 3. Construct: r=.92 with age
High-Level Mobility Assessment Tool	Yes	1. Interrater, 2. Test-retest	1. ICC=.93, 2. ICC=.98	Yes	Concurrent	52 children with traumatic brain injury	Spearman ρ=.68 with PEDI functional skills mobility domain
Limits of Stability Test	Yes	Test-retest	ICC=.73	Yes	Construct (divergent and discriminant)	36 adolescents	No significant correlations with BESS total score (P>.05)
Modified Star Excursion Balance Test	Yes	Test-retest	ICC range, .51−.93	No	N/A	N/A	N/A

(*continued on next page*)

Supplemental Table S2 (*continued*)

Measure	Reliability Tested	Reliability Type	Reliability Score	Validity Tested	Validity Type	Validity Sample Size	Validity Score
One Leg Standing Balance Test	Yes	1. Interrater, 2. Test-retest	1. Eyes open $r=1.00$, eyes closed $r=.96$; 2. Eyes open $r=.91$—1.00; eyes closed $r=.59$—.77	No	N/A		N/A
Pediatric Balance Scale	Yes	1. Interrater, 2. Test-retest	1. ICC=.997, 2. ICC=.998	No	N/A	N/A	N/A
PRT	Yes	1. Interrater, 2. Test-retest	1. ICC range, .50—.93, 2. ICC range, .54—.88	Yes	1. Concurrent, 2. Construct	29 children (19 developing typically, 10 with CP)	1. Construct: $r=.79$ with a laboratory test of steadiness in quiet stance and $r=.83$ with age, Spearman $\rho=0.8$ with GrossMotor Function Classification System among the sample of children with cerebral palsy; 2. Concurrent: $r=.42$—.77 between the standing section of the PRT and laboratory tests of limits of stability
Pediatric Version of Clinical Test of Sensory Interaction for Balance	Yes	Interrater	Spearman ρ range, .69 (feet together) to .92 (heel-toe)	No	N/A	N/A	N/A
Posture and Postural Ability Scale	Yes	1. Interrater, 2. Internal consistency	1. ICC=.77, 2. Cronbach $\alpha=.95$—.96	Yes	Construct	29 children with cerebral palsy	Significantly differentiated between Gross Motor Function Classification System scores ($P<.009$)
Sensory Organization Test	No	N/A	N/A	Yes	Discriminant	20 children with sever to profound sensorineural hearing loss, 23 children developing typically	Discriminated between children with sensorineural hearing loss and those with typical development (sensitivity, .75; specificity, .86)
Sensory Test	Yes	1. Test-retest	ICC range, .76—.90	No	N/A	N/A	N/A

(*continued on next page*)

Supplemental Table S2 (*continued*)

Measure	Reliability Tested	Reliability Type	Reliability Score	Validity Tested	Validity Type	Validity Sample Size	Validity Score
Timed Up and Down Stairs Test	Yes	1. Interrater, 2. Test-retest	1. ICC = .99, 2. ICC = .94	Yes	1. Concurrent, 2. Construct	47 children (20 with cerebral palsy and 27 developing typically)	1. Concurrent: $r = .78$ with TUG, $r = -.57$ with FRT and $r = -.77$ with TOLS; 2. Construct: moderate correlation with age (r range, .61–.41; $P = .001$ and $P = .018$, respectively)
TUG	Yes	Test-retest	ICC = .83 for children without physical disabilities, ICC = .099 same-day retest for children with disabilities	Yes	Concurrent	Subgroup of 22 young adults with cerebral palsy concurrently tested using the GMFM	Moderate negative correlation between TUG scores and the GMFM ($\rho = .524$, $P = .012$)
Early Clinical Assessment of Balance				Yes	1. Content; 2. Construct	410 children with cerebral palsy across all GMFCS Levels; age, 1.5–5y	1. Content: test item correlation range, .32–.94 ($P < .0001$); Cronbach $\alpha = .92$; 2. Construct: significant differences in test scores between GMFCS groups ($\chi^2 = 365.11$, $P < .001$)

Abbreviations: BESS, balance error scoring system; FASD, fetal alcohol spectrum disorder; FRT, Functional Reach Test; GMFCS, gross motor function classification system; GMFM, Gross Motor Function Measure; ICC, intraclass correlation coefficient; N/A, not available; M-ABC-2, movement assessment battery for children, second edition; PEDI, pediatric evaluation of disability inventory; PRT, Pediatric Reach Test; PT, physical therapist; TUG, Timed Up and Go test; TOLS, timed one leg stance test.